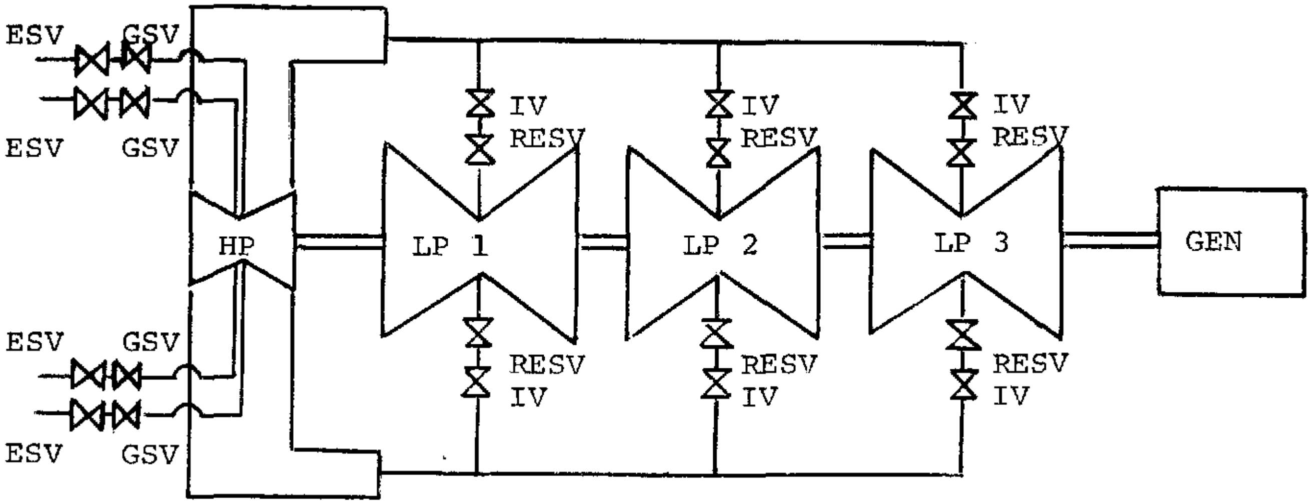
Turbine, Generator & Auxiliaries - Course 134

RELIABILITY AND TESTING REQUIREMENTS



ESV = Emergency Stop Valve
GSV = Governor Steam Valve

IV = Intercept Valve
RESV = Reheat Emergency Stop Valve

CONTROL VALVES

Figure 6.1

Figure 6.1 shows the layout of the turbines and steam valves associated with a large generating station. The ability of these valves to quickly and reliably shutdown the turbine unit on a fault is important to the safety of not only the turbine but also the personnel and equipment surrounding the turbine. This is of particular significance in the case of a turbine overspeed because of the possibility of blade wheel failure which may result in pieces of the wheel being thrown through the casing. In the casualties of this type which have occurred around the world the following has been typical:

(a) significant personnel injury in a majority of the cases,

(b) fatalities in several cases,

(c) blade wheel fragments being thrown through the casing and turbine hall wall, with some pieces travelling up to a quarter of a mile, and

(d) lubricating oil and generator hydrogen fires.

In addition, in nuclear stations there is a growing concern with the possibility of an unterminated overspeed casualty causing missiles which could cause failure of components in the nuclear steam supply system. This latter consideration is of sufficient public safety concern to warrant the AECB setting a target for the maximum allowable frequency of unterminated turbine overspeed incidents of 10^{-4} events per year. That is, that a turbine unit must experience an unterminated overspeed incident no more frequently than once in 10,000 years. Experience has shown that potential overspeed incidents (for example a loss of output line) occur approximately once per year. In order to meet the AECB target for unterminated overspeed incidents, it is necessary to prove that the unavailability of the system to arrest a potential overspeed is less than 10^{-4}.

This lesson will discuss the general approach which must be taken in establishing a testing frequency for the turbine components associated with overspeed protection in order to meet this target frequency.

THE PROBLEM

If the generator load is lost through the opening of the output breaker, the counter torque which the load current exerts on the generator rotor is lost. Unless the steam supply to both the high pressure and low pressure turbine are rapidly shut off, the turbine speed rapidly increases and in a matter of seconds reaches a point between 175% and 200% of operating speed where the stress on the largest wheels in the low pressure turbines exceeds the ultimate tensile strength of the metal. At this point the blade wheel ruptures into several large fragments (60° to 120°) and many smaller ones. These pieces may be thrown through the casing severing steam lines and lube oil lines. At this point the overspeed will be terminated and the unit will begin to slow down.

OPERATION OF THE OVERSPEED TRIP

The response to an overspeed condition varies from plant to plant depending on the type of governing system (mechanical-hydraulic or electrical-hydraulic) and the fluid which operates the control valves (lubricating oil, fire resistant fluid or air). However, the large nuclear steam turbine units operated by Ontario Hydro have the following common characteristics:

(a) High pressure steam is admitted to the turbine through four main steam lines. Each of these lines has an emergency stop valve and a governor steam valve in series.

(b) Low pressure steam exits from the high pressure turbines and, after passing through the moisture separator and reheater, enters the three low pressure turbines. Each low pressure turbine has two steam input lines and each of these six low pressure steam lines has an intercept valve. (In the case of the Bruce Nuclear Generating Station which is shown in Figure 6.1, there is a reheat emergency stop valve in series with each intercept valve).

(c) Regardless of the action taken by the overspeed protection devices, if the turbine speed rises to between 110% and 112% of operational speed, a tripping device, using a spring loaded, centrifugally operated overspeed bolt, operates and shuts all of the valves.

(d) Because there is more than one steam line associated with steam admission to each turbine, any single line can be closed at power without appreciably effecting the unit output. This permits on-load testing of each valve.

ANALYSIS

The unavailability of a particular valve can be related to its failure rate and the interval between tests by the formula

$$Q_i = \frac{\lambda_i T_i}{2} \qquad 6.1$$

where: Q_i = Unavailability of Valve i

λ_i = Failure Rate (per annum) of Valve i

T_i = Interval Between Tests (in years) of Valve i

This relationship assumes that on the average a failed valve has been in that condition for half the test interval before being found and corrected on the next test. It is obvious from the equation that as the failure rate of the valve decreases or the interval between testing decreases, the unavailability of the valve decreases. That is, frequent testing and a reliable valve will minimize the probability of a valve failing to operate when called upon (Unavailability).

VALVE UNAVAILABILITY

Referring to Figure 6.1, if steam fails to be shut off to the high pressure turbine <u>in a particular inlet line</u> then both the governor steam valve (GSV) and the emergency stop valve (ESV) in that line must be unavailable. So the unavailability associated with a particular high pressure inlet line is:

$$Q_{LINE} = Q_{GSV} Q_{ESV} \qquad 6.2$$

Similarly, if steam fails to be shutoff to the low pressure turbine in a particular inlet line then both the intercept valve (IV) and the reheat emergency stop valve (RESV) in that line must be unavailable. So the unavailability associated with a particular low pressure inlet line is

$$Q_{LINE} = Q_{IV}\ Q_{RESV} \qquad 6.3$$

It can be seen that by having both an intercept valve and a reheat emergency stop valve in the inlet lines to the low pressure turbine the unavailability associated with each line is considerably reduced.

For a successful turbine trip, all ten of these lines must shut. So the unavailability of the valving for proper shutdown of the unit is given by the expression

$$Q_{VALVING} = 4\ Q_{GSV}\ Q_{ESV} + 6\ Q_{IV}\ Q_{RESV} \qquad 6.4$$

Table 6.1 summarizes valve failure rate data based on past testing and the unavailability of the steam valve system for various test intervals.

TABLE 6.1

STEAM ADMISSION VALVE UNAVAILABILITY

TEST INTERVAL	PREDICTED UNAVAILABILITY
1 Week	2.3×10^{-6}
2 Weeks	9.2×10^{-6}
1 Month	4.3×10^{-5}
3 Months	3.8×10^{-4}

$$Q_{VALVING} = 4\ Q_{GV}\ Q_{ESV} + 6\ Q_{IV}\ Q_{RESV}$$

COMPONENT	PREDICTED FAILURE RATE
Governor Steam Valve	.07/annum
Emergency Stop Valve	.07/annum
Intercept Valve	.04/annum
Reheat Emergency Stop Valve	.03/annum

TRIP LOGIC UNAVAILABILITY

In the turbine unit shown in Figure 6.1, all of the valves are held open against spring tension by a fire resistant fluid (FRF) system. On a overspeed condition, the

FRF pressure is dumped from the underside of the valve operating pistons and spring tension drives the valve shut. The tripping circuit is composed of two independent channels either one of which is capable of dumping the FRF and shutting all 20 of the valves. The two trip channels are interlocked to prevent both channels being tested at the same time.

Figure 6.2 shows a simplified arrangement of the turbine tripping system. Each channel consists of:

(a) an overspeed sensor in the form of a spring loaded, centrifugally operated overspeed bolt mounted on the HP turbine rotor,

(b) a spring loaded pilot trip plunger,

(c) a mechanical linkage between the overspeed bolt and the pilot trip plunger,

(d) a spring loaded main trip plunger,

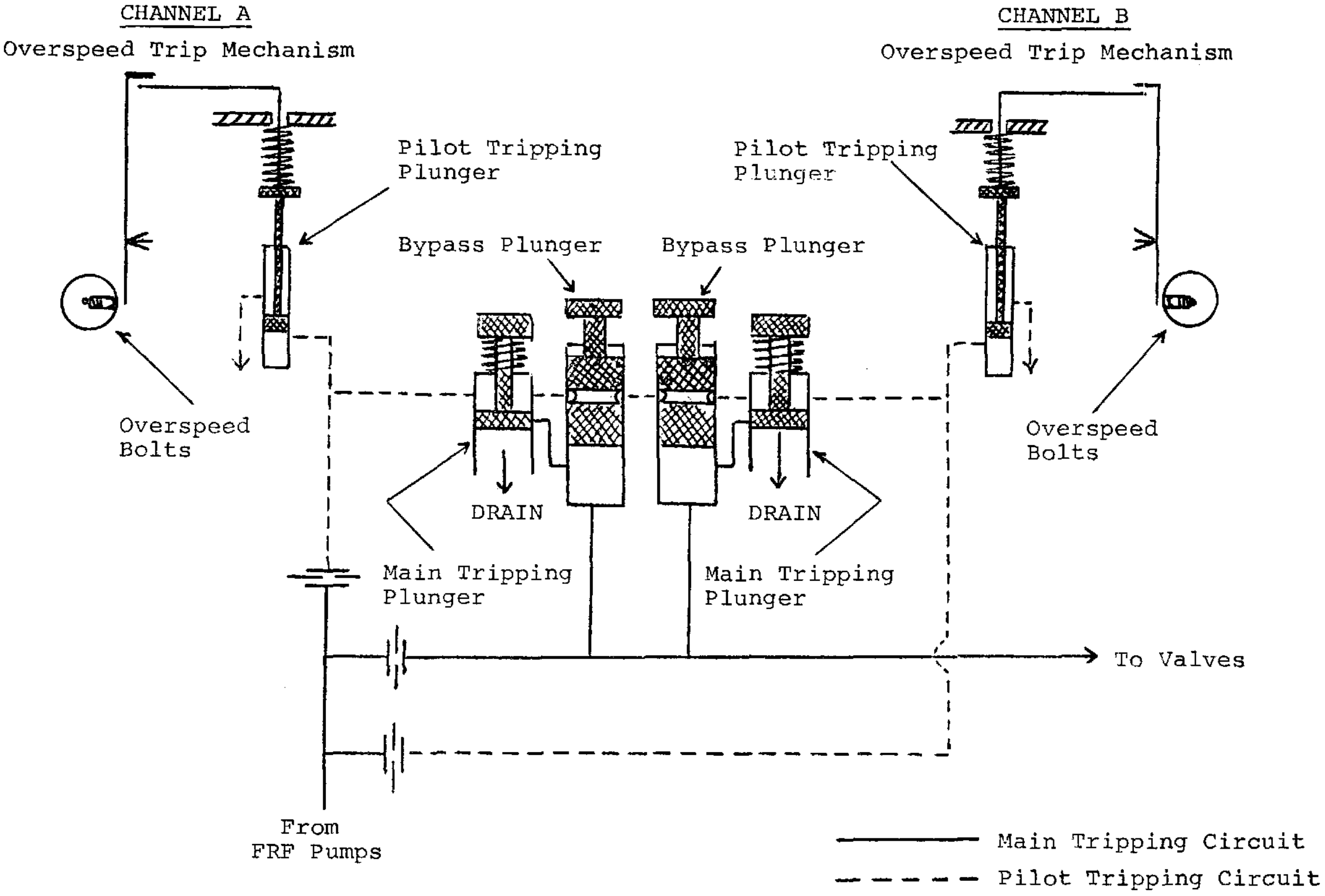
(e) a spring loaded bypass plunger, used to gag a channel for test, and

(f) an FRF circuit called the pilot tripping circuit.

The drawing shows all equipment in its normal operating state. The pilot trip plunger is held up against spring tension by a mechanical linkage shown on the drawing as the "overspeed trip mechanism". In the up position the pilot trip plunger isolates the pilot tripping circuit (dashed line) from the drain, thereby keeping the pilot circuit pressure up. The pilot tripping circuit pressure forces the main trip plunger down against its spring. In this position, the main trip plunger isolates the main tripping circuit from the drain on the underside of the main trip plunger.

On an overspeed, centrifugal force overcomes the spring tension on the overspeed bolts and forces them out to eventually contact the "overspeed trip mechanism". The overspeed trip mechanism releases the pilot trip plunger and allows it to spring down and release the pilot tripping pressure to drain. As the pilot tripping pressure is reduced, the main trip plunger springs up opening the main tripping circuit to drain. The falling pressure in the main tripping circuit trips the steam admission valves.

Because the pilot tripping circuit for Channel A and B are connected to both main trip plungers, a trip on either channel will trip both main tripping plungers to dump. This design makes the system less suseptible to main trip plunger failure since either trip plunger can receive a trip signal from either overspeed bolt.



OVERSPEED TRIPPING CIRCUIT

Figure 6.2

Bypass plungers are provided to allow on-power testing of the tripping circuit. Depressing the bypass plunger for a channel:

(a) gags the channel by isolating the main tripping plunger for that channel from the main tripping circuit, and

(b) isolates the pilot tripping plunger of the channel to be tested from the main tripping plunger of the other channel.

It is then possible to test the entire trip channel without tripping the turbine and without totally disabling the turbine trip system. Routine on line tests of the overspeed trip is accomplished by forcing the bolts out under oil pressure. The oil pressure required to trip the channel under test is then correlated to an operating speed.

It can be seen that an overspeed trip channel can be rendered unavailable by any of the following:

(a) Overspeed Bolt (OSB) fault

(b) Trip Linkage (TL) fault

(c) Pilot Trip Plunger (PTP) fault

(d) Main Trip Plunger (MTP) fault

(e) Bypass Plunger (BP) fault

(f) Testing (T)

Thus, the unavailability of either overspeed Channel, A or B, can be expressed as

$$Q_A = Q_B = Q_{OSB} + Q_{TL} + Q_{PTP} + Q_{MTP} + Q_{BP} + Q_T \qquad 6.5$$

Since either overspeed trip channel is capable of effecting a successful turbine trip, the unavailability of both channels is approximately

$$Q_Z = (Q_{OSB} + Q_{TL} + Q_{PTP} + Q_{MTP} + Q_{BP} + Q_T)^2 \qquad 6.6$$

Equation 6.6 makes two symplifying, and conservative, assumptions:

(a) that both channels can be in test simultaneously (they cannot)

(b) that the overspeed bolt on one channel cannot trip the main tripping plunger on the other channel (they can)

TABLE 6.2

TRIP SYSTEM UNAVAILABILITY

TEST INTERVAL	PREDICTED UNAVAILABILITY	
	One Channel	Both Channels
1 Week	7.4×10^{-3}	5.5×10^{-5}
2 Weeks	5.7×10^{-3}	3.3×10^{-5}
1 Month	7.3×10^{-3}	5.3×10^{-5}
3 Months	1.8×10^{-2}	3.2×10^{-4}

$$Q_A = Q_B = Q_{OSB} + Q_{TL} + Q_{PTP} + Q_{MTP} + Q_{BP} + Q_T$$

$$Q_Z = (Q_{OSB} + Q_{TL} + Q_{PTP} + Q_{MTP} + Q_{BP} + Q_T)^2$$

COMPONENT	PREDICTED FAILURE RATE
Overspeed Bolt	.04/annum
Trip Linkage	.01/annum
Pilot Trip Plunger	.04/annum
Main Trip Plunger	.04/annum
Bypass Plunger	.01/annum
Testing	1 hour/test/channel

Table 6.2 summarizes the failure rate of tripping circuit components based on past testing and the unavailability of the tripping system for various test intervals. From this table it can be seen that monthly testing of the overspeed trip circuit is quite satisfactory. More frequent testing can effect, at most, only a modest decrease in unavailability and can actually cause an increase in unavailability due to the fact that a channel must be gagged to test it. Testing at three month intervals is unacceptible since it results in a trip circuit unavailability which alone (not including valve unavailability) exceeds the specified target unavailability of 10^{-4}.

SHUTDOWN SYSTEM UNAVAILABILITY

Overall overspeed trip unavailability is simply the sum of the unavailability contributions from the valves and the tripping circuit. Table 6.3 summarizes the system unavailability for various testing intervals and indicates monthly testing is the minimum frequency which will meet the target unavailability.

TABLE 6.3

OVERSPEED TRIP UNAVAILABILITY

TEST INTERVAL	PREDICTED UNAVAILABILITY
1 Week	5.7×10^{-5}
2 Weeks	4.2×10^{-5}
1 Month	9.6×10^{-5}
3 Months	7.0×10^{-4}

$Q_T = Q_Z + Q_{VALVING}$

ASSIGNMENT

1. Explain how equation 6.4 would be altered if the governor steam valves could not, by design, operate fast enough to prevent a potential overspeed from reaching an unacceptible high speed?
2. What would be the effect on the unavailability of the total overspeed protection system (valves and tripping circuit) if a 3 channel tripping circuit were used? a 6 channel circuit? an infinite channel circuit? (Calculations are not necessary)
3. What is the practical consequences of having a large number of tripping circuit channels?
4. Explain how equation 6.4 would be altered if a successful turbine trip was achieved if only five of the six low pressure inlet lines were to shut.

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